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Biofuels

Vertical Distribution of Corn Biomass as Influenced by Cover Crop and Stover Harvest

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ABSTRACT

Corn (*Zea mays* L.) production for grain is important given its many uses for human food, animal feed, and other industrial products. Additionally, the abundance and potentially large biomass yield makes corn an attractive bioenergy feedstock. The objective of this study was to evaluate the effect of in-season weather conditions, rye (*Secale cereale* L.) as a winter cover crop, and corn residue harvest on grain yield and biomass distribution across two soil types. Grain, as well as, total and partial stover yields (below the ear, above the ear excluding cobs, cobs alone, and above the ear including top and cobs) were measured from 2009 to 2011 at two sites with different soil types: loamy sand and silt loam, in central and northern Alabama, respectively. Significant differences in grain and biomass yields were observed among individual years and locations. Grain yields were positively correlated with seasonal cumulative precipitation and negatively with seasonal average temperature at both locations. In central Alabama, the 3-yr use of a rye cover crop increased corn biomass yields compared to rye removal while there was no difference compared to plots without a rye cover crop. The 3-yr corn residue management effect was not significant at any location. Based on this study, harvesting the above-ear corn plant fraction could be an attractive option for partial biomass harvesting in southeastern United States.

Biofuel production from biomass seems to be an alternative solution to mitigate fossil fuel use and to reduce greenhouse gas emissions. However, growing food crops like corn grain, soybean [*Glycine max* (L.) Merr.], and cereals for biofuel production would compete with land use for food production. Cellulosic biomass derived from crop residues would not compete with food use since both can be produced simultaneously; therefore, it seems to be a promising alternative renewable source of energy.

Corn is a promising crop for biomass production. Biomass and grain yield could be affected by factors such as weather conditions, nutrient availability, winter cover crop rotation, and residue harvest. Rye is a well-known winter cover crop known for its superior winter hardiness, its sensitivity to herbicide kill, and its consistent large residue production (Moschler et al., 1967; Odhiambo and Bomke, 2001). The impact of rye as a winter cover crop on corn productivity varies with geographic location. A study in Canada indicated that a rye cover crop resulted in significantly lower corn grain and biomass yield (Raimbault et al., 1990). Another study conducted in the northern United States by Bundy and Andraski, (2005) reported that whole corn plant biomass was not significantly affected by the use of rye as a winter cover crop. However, other studies in the Southeast indicated that using cover crops can improve soil productivity, especially when combined with conservation tillage practices (Bruce et al., 1995; Sainju et al., 2002).

Corn stover is composed of the stalk, leaves, cobs, and husks. The stalk, which accounts for more than 50% of the total biomass, is the largest fraction of the stover. The remaining portion is composed of leaves, cobs, and husk (Atchison and Hettenhaus, 2003; Masoero et al., 2006). Shinners and Binversie (2007) found that the stalk accounts for 56% of the stover dry weight, the cob for 15%, the husk for 8%, and the remaining 21% is leaves. An older study reported that stalks, leaves, and tassels account for 70% of total corn stover biomass, with the remaining 30% being husks, shanks, silks, and cobs (Hanway, 1963). Similar results have been found in more recent studies. Pordesimo et al. (2005) found that the highest corn stover biomass occurred at the time of grain physiological maturity, around 118 d after planting. The aboveground biomass distribution, including grain, was 46% grain, 28% stalk, 11% leaf, 8% cob, and 7% husk (grain:stover = 0.85:1). Without considering grain, the biomass distribution in stover was 51% stalk, 21% leaf, 15% cob, and 13% husk.

Corn biomass remaining in the field after the growing season is very important for erosion control, C sequestration, and

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Abbreviations: EVS, E.V. Smith Research Center; SOC, soil organic carbon; T, tasseling growth stage; TVS, Tennessee Valley Research and Extension Center.

nutrient cycling, which all affect soil productivity (Johnson et al., 2007, 2009; Lindstrom, 1986; Wilhelm et al., 2004). To balance these multiple soil demands, a portion of the biomass could be harvested for biofuel production, while the rest should be left in the field to enhance formation of organic C. Combines that harvest grain, as well as, stover or part of the stover have already been developed (Hoskinson et al., 2007). In large-scale biomass production, it is difficult to harvest specific parts of the plant like husks alone or leaves without the stalk. It is more feasible to harvest a specific portion, for example, the bottom; cobs; top part of the plant alone; or top and cobs together.

Cobs are an attractive bioenergy feedstock. They contain approximately 19.18 MJ kg^{-1}, while the total stover biomass contains energy up to 17 MJ kg^{-1} (Zych, 2008). Cobs can be harvested by existing equipment and they are sufficiently dense that they do not require densification (Zych, 2008). Intuitively, cobs are a highly desirable portion of corn residue as a feedstock for bioenergy production. Despite the attractive characteristics of cobs as a bioenergy feedstock, the relative low yield per unit area can be a disadvantage for biofuel production. However, when the top fraction was combined with the cobs, the result was greater yield per unit area while including the desirable compositional characteristics of cobs. There have been studies that indicated that the above-ear portion of the stover have the most desirable composition for cellulosic ethanol production (Duguid et al., 2009; Hoskinson et al., 2007; Johnson et al., 2010, Mourtzinis et al., 2014), and therefore, identification of a management practice that would maximize the yield of that portion would be of great importance.

However, partially harvesting corn biomass for an extended period could negatively impact soil productivity. Sustaining soil organic carbon (SOC) and crop productivity will greatly depend on the amount of stover harvested. The use of rye as a winter cover crop could mitigate these impacts. Nevertheless, the response of total and partial biomass yield could vary between locations with different climates, soil types, and management practices (e.g., use of winter cover crops and corn residue harvest). Therefore, the first objective of this experiment was to examine if and how the corn grain and stover yields were correlated with in-season weather conditions under different cover crop management practices within two soil types in Alabama. The second objective of this experiment was to determine the impact of selected cropping practices, including stover harvest and use of cover crops, on grain, total and partial biomass yields at two locations in Alabama. The third objective was to determine the vertical distribution of corn biomass under different cultivation techniques and soil types. This information can be useful for developing of stover harvest recommendations that could be used as a decision-making tool for the biofuel industry and farmers who wish to harvest corn stover sustainably.

MATERIALS AND METHODS

Site Description

Vertical distribution of corn biomass was assessed at two locations in Alabama. The first location was the E.V. Smith Research Center (EVS) in central Alabama (32.43 N, −85.89 W) with a mean annual precipitation (MAP) of 1330 mm and mean annual temperature (MAT) of 18°C. The second location was the Tennessee Valley Research and Extension Center (TVS) in Belle Mina (34.69 N, −86.89W) in the northern part of the state with MAP of 1380 mm and MAT of 16°C. The soil at EVS was a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudult), while at TVS, the soil was a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudult).

The trials were conducted on the same area each year. Plots were arranged in a split-plot design with three replications. Main plots consisted of cereal rye as a winter cover with three levels (no cover, rye as a cover crop harvested in spring, and rye retained after chemical termination with glyphosate), and subplots were two corn residue removal levels (0 and 100% removal). The subplot size was 16.7 m^2. A single N fertilizer rate of 168 kg ha^{-1} was applied to all plots which is the recommended rate for corn planted into small grain stubble (ACES, 1994). Urea ammonium nitrate (UAN 28−0−0) was used as the N fertilizer source with the total amount applied split in two equal portions early in the growing season, approximately 2 and 5 wk after planting. In late winter of every year, 34 kg ha^{-1} N was applied to all plots with cereal rye as a winter cover to maximize production of rye biomass. Phosphorus and K fertilizers were applied as needed based on ACES recommendations for corn from soil test results. Both locations were under non-irrigated continuous corn production and the target plant population was 70,000 plants ha^{-1}. At TVS, plots were under no-tillage corn production while at EVS, strip-till and subsoiling was performed annually to 30- to 40-cm deep. Corn was planted in late March to early April, and cultural practices were performed according to ACES recommendations to maximize corn yield. Corn residue removal was performed every year after grain harvest early in the fall. In the residue harvested plots, which were the smallest plots nested in rye treatments, all corn biomass was removed using a rake attached on a tractor.

Data Collection

Square steel frames measuring 0.25 m^2 were used to sample the rye. Eight frames/samples from each main plot were taken every spring for rye biomass determination. Plots assigned the no rye treatment were sampled to determine the biomass of winter weeds.

Whole corn plant samples were taken at harvest from a representative area of every plot, consisting of a 1-m length of row from both middle rows, for biomass determination. Corn grain was partitioned from the cobs and the rest of the stalk. Plants were further separated into four fractions: below the ear (bottom); above the ear excluding cobs (top); and the cobs alone. An additional plant portion (above-ear) was calculated by summing the top and cob dry yields to determine the dry biomass of this crop portion. Samples were oven dried for 7 d at 55 to 60°C until constant weight and weighed to determine dry weight. Grain yield was adjusted to 15.5% moisture content, while biomass is reported on a dry matter basis. Daily precipitation and air temperature data were collected from weather stations located at each experimental site (Alabama Mesonet Weather network). Cumulative precipitation (mm) and average air temperature at 1.5 m aboveground from May to August were calculated and used as independent variables.

Statistical Analysis

The CORR procedure in SAS 9.3 (SAS for Windows v. 9.3, SAS Institute Inc., Cary, NC) was used to detect correlations of weather conditions during the growing season with corn grain and biomass yields. Analysis of variance was performed using the GLIMMIX procedure to detect differences in grain and biomass yields between and within locations as affected by rye cover crop and residue removal treatments. The six variables of interest included: grain yield (grain), total biomass (stover), bottom portion of the plant biomass (bottom), top portion of the plant biomass excluding cobs (top), cobs alone (cob), and the above the first ear portion of the plant biomass including cobs (above-ear). The following variables were considered as random effects: location, year, replication, and their interactions with residue management, cover crop, and residue management × cover crop. A factor was considered significant at level lower than 0.10 ($\alpha < 0.10$).

RESULTS AND DISCUSSION

Rye Biomass Yield

Rye yields varied between both locations every year. Yields were consistently greater at EVS compared to TVS every year the experiment was conducted. Overall, rye yield at EVS ranged between 1503 and 6275 kg ha^{-1} with an average of 3343 (std ± 2064) kg ha^{-1} for the 3 yr of the study. At TVS, the corresponding yield range was 1937 to 3281 kg ha^{-1} with an average of 2475 (std ± 487) kg ha^{-1}. This wide range in rye biomass production between years can mainly be attributed to temperature differences between year and locations during the winter months, with colder seasons producing less biomass than warmer ones. However, these yields were similar to those reported by Duiker and Curran (2005) in a silt loam soil.

Winter weeds grew in plots assigned to no rye treatment. Since weeds often affect corn productivity, weed biomass with no rye was measured at the same time as rye biomass. At EVS, weed biomass ranged between 900 and 1200 kg ha^{-1} with an average yield of 1030 (std ± 157) kg ha^{-1}, while at TVS yields ranged between 370 and 880 kg ha^{-1} with an average yield of 625 (std ± 255) kg ha^{-1}.

Effect of In-Season Weather

In Alabama, one of the most limiting factors in corn production is the lack of adequate water. However, crop residues that cover 30% or more of the soil surface can reduce water losses due to evaporation (ACES, 1994). Therefore, correlation of corn yields with in-season weather conditions can vary in plots with a cover crop compared to plots without a cover crop.

Cumulative precipitation levels and average temperatures varied over the six location–years (Table 1). At EVS, total precipitation and average temperatures were consistently higher than those at TVS during all three growing seasons. At EVS, the effect of weather conditions on corn yields varied among rye treatments (Table 2). Correlations between precipitation and temperature with grain and stover yields were significant and stronger in no rye and rye removed plots than plots where rye was retained. This highlights that using a cover crop might reduce the impact of weather on corn productivity. Nevertheless, the direction of the correlations was consistent between rye treatments, regardless of whether rye was retained, removed, or not used at all. The strongest negative correlations between corn yields and air temperatures were detected in plots where rye was removed in spring and in plots without a cover crop. This negative correlation between air temperature and yield underscores the impact of heat stress on corn productivity. Furthermore, this is an indication that when rye is retained in the field, it has the potential to lower the daily maximum soil temperature, especially in June and July that corresponds to a critical period of development for corn. Similar results have also been reported by Teasdale and Mohler (1993).

Different strength of correlations among rye treatment levels was also observed at TVS (Table 3). Grain yields exhibited similar correlations with weather conditions to EVS. However, stronger correlations between grain yields and weather conditions were detected where rye was retained in the field. Stover yields were positively correlated with cumulative precipitation in June and negatively correlated with cumulative seasonal precipitation and precipitation in July and August. This response varied from what was observed at EVS. Differences in soil types between the two locations could explain these variations. The soil at EVS was a loamy sand and has lower water retention capacity than the silt loam at the TVS location. Given the texture of the soil at EVS, more frequent rainfall required for corn plants to have an adequate water supply during the growing season. This could partially explain the positive correlation between yields and precipitation. However, the silt loam soil at TVS has a greater ability to retain water than the loamy sand. Large precipitation events during the growing season could result in flooding and therefore, reduce corn yield. For example, flooding during the tasseling growth stage (VT) in 2009 and in 2011, could explain the observed negative correlations between yield and amount of rainfall.

A rye cover crop retained in the field could reduce moisture losses due to less evaporation and cooler soil temperatures (Teasdale and Mohler, 1993). Stronger correlations between corn yields and weather conditions without a rye cover crop could indicate a higher vulnerability of yields to in-season weather. For example, corn yields increased with increasing precipitation and decreased with increasing temperatures in the no cover treatment at EVS. Similar strong correlations were observed where rye was removed in spring. However, there was no significant correlation where rye was present. In such scenarios, rye could reduce heat stress and plant water stress due to decreased evaporation, both of which could impact corn yields. Thus, it seems that rye retained in the field could be used as a management practice to reduce the impact of year-to-year weather variability on corn productivity.

Corn Grain Yield

Grain yields varied significantly between locations and years (Table 4). At all 6 site-years, grain yields were numerically greater in plots where rye or stover was retained (Tables 5 and 6). Nevertheless, not all the differences were statistically significant. More specifically at EVS, the effect of rye, stover management, and their interaction did not increase yields in 2009 (Table 5). During the second year, the grain yield was the greatest ($p = 0.0473$) where the stover was retained. The same trend was also observed in 2011; however, the use of a rye cover crop was the only significant factor ($p = 0.0940$).

Table 1. Seasonal and monthly cumulative precipitation, and seasonal and monthly (May–August) average temperature during the three growing seasons at E.V. Smith Research Center (EVS) near Shorter in central Alabama, and at Tennessee Valley Research and Extension Center (TVS) near Belle Mina in northern Alabama.

		Precipitation					Temperature				
Location	Year	Season	May	June	July	August	Season	May	June	July	August
		mm					°C				
	2009	976	262	100	75	192	24.3	23.0	21.7	26.6	26.7
EVS	2010	514	176	56	128	122	25.8	24.1	28.0	29.1	29.3
	2011	426	56	57	204	16	26.4	21.9	28.3	28.3	28.4
	2009	808	242	28	140	106	22.6	20.7	25.9	24.9	25.1
TVS	2010	367	138	57	94	31	24.8	21.9	26.7	27.9	28.6
	2011	329	42	79	109	29	25.5	21.7	26.8	27.6	26.6

Table 2. Three-year average Pearson correlations (*r* values) of corn grain and stover yields with seasonal cumulative precipitation, seasonal average air temperature, monthly (May–August) cumulative precipitation, and monthly average air temperature during the growing season at E.V. Smith Research Center (EVS) near Shorter in central Alabama when rye was retained as a cover crop and plots without rye.

Weather attribute	Rye treatment					
	Rye removed					
Precipitation	Grain†	Stover	Bottom	Top	Cob	Above-ear
Season	0.73***	0.61***	–0.05	0.76***	0.63***	0.77***
May	0.70***	0.56**	–0.10	0.71***	0.64***	0.74***
June	0.79***	0.81***	0.32	0.90***	0.48**	0.85***
July	–0.70***	–0.55**	0.11	–0.70***	–0.64***	–0.74***
August	0.69***	0.54**	–0.12	0.69***	0.64***	0.73***
Temperature						
Season	–0.74***	–0.82***	–0.47**	–0.88***	–0.34	–0.80***
May	0.10	–0.16	–0.62***	–0.04	0.42*	0.08
June	–0.80***	–0.80***	–0.29	–0.90***	–0.50**	–0.85***
July	–0.72***	–0.81***	–0.50**	–0.86***	–0.32	–0.78***
August	–0.72***	–0.81***	–0.50**	–0.86***	–0.32	–0.78***
	Rye retained					
Precipitation	Grain	Stover	Bottom	Top	Cob	Above-ear
Season	0.31	–0.07	–0.47*	0.27	0.25	0.27
May	0.26	–0.13	–0.53*	0.21	0.23	0.22
June	0.59**	0.31	–0.04	0.57*	0.33	0.53*
July	–0.25	0.13	0.54*	–0.20	–0.22	–0.22
August	0.24	–0.15	–0.55*	0.19	0.22	0.21
Temperature						
Season	–0.67**	–0.48*	–0.20	–0.67**	–0.33	–0.601**
May	–0.39	–0.65**	–0.86**	–0.44‡	–0.07	–0.35
June	–0.58*	–0.28	0.08	–0.55*	–0.33	–0.51*
July	–0.69**	–0.50**	–0.24	–0.68**	–0.33	–0.61**
August	–0.69**	–0.51**	–0.24	–0.68**	–0.33	–0.61**
	No rye					
Precipitation	Grain	Stover	Bottom	Top	Cob	Above-ear
Season	0.43‡	0.36	–0.04	0.58**	0.69**	0.64**
May	0.37	0.30	–0.12	0.52**	0.68**	0.60**
June	0.70**	0.71**	0.42‡	0.79***	0.68**	0.80**
July	–0.36	–0.29	0.13	–0.52*	–0.68**	–0.59**
August	0.35	0.27	–0.14	0.51*	0.67**	0.58*
Temperature						
Season	–0.76**	–0.81**	–0.61**	–0.82**	–0.59*	–0.79**
May	–0.34	–0.47*	–0.78**	–0.20	0.22	–0.09
June	–0.68**	–0.68**	–0.38	–0.78**	–0.68**	–0.79**
July	–0.77**	–0.82**	–0.64**	–0.82**	–0.57*	–0.78**
August	–0.77**	–0.82**	–0.64**	–0.81**	–0.57*	–0.78**

* Significance at 0.05 probability level.

** Significance at 0.01 probability level.

*** Significance at 0.001 probability level.

† Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top– biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear–biomass yield of tops and cobs combined.

‡ Significance at 0.10 level.

Table 3. Three-year average Pearson correlations (**r** values) of corn grain and stover yields with seasonal cumulative precipitation, seasonal average air temperature, monthly (May–August) cumulative precipitation, and monthly average air temperature during the growing season at Tennessee Valley Research and Extension Center (TVS) near Belle Mina in northern Alabama when rye was retained as a cover crop and plots without rye.

Weather attribute	Rye treatment					
	Rye removed					
Precipitation	Grain†	Stover	Bottom	Top	Cob	Above-ear
Season	0.17	0.57**	–0.63**	–0.49*	–0.26	–0.41‡
May	0.02	–0.36	–0.41‡	–0.35	–0.18	–0.25
June	0.35	0.40‡	0.46**	0.38‡	0.20	0.29
July	–0.32	–0.83**	–0.88**	–0.62**	–0.36	–0.61**
August	–0.21	–0.70**	–0.76**	–0.56**	–0.31	–0.51*
Temperature						
Season	0.19	0.83**	0.88**	0.62**	0.35	0.61**
May	0.13	0.80**	0.85**	0.61**	0.34	0.58**
June	–0.03	0.70**	0.75**	0.56**	0.31	0.51*
July	0.06	0.75**	0.81**	0.59**	0.33	0.55*
August	0.38‡	0.87**	0.90**	0.60**	0.36	0.64**
	Rye retained					
Precipitation	Grain	Stover	Bottom	Top	Cob	Above-ear
Season	0.64***	–0.69**	–0.74**	–0.48‡	–0.35	–0.57*
May	0.67***	–0.57*	–0.58*	–0.37	–0.41	–0.53*
June	–0.67**	0.59*	0.61*	0.39	0.40	0.54*
July	0.45‡	–0.82**	–0.94**	–0.60*	–0.16	–0.57*
August	0.59*	–0.76**	–0.84**	–0.54*	–0.29	–0.59*
Temperature						
Season	–0.47‡	0.82**	0.93**	0.60*	0.17	0.57*
May	–0.51*	0.81**	0.91**	0.58*	0.21	0.58*
June	–0.59*	0.76**	0.84**	0.54*	0.29	0.59*
July	–0.55*	0.79**	0.88**	0.57*	0.25	0.59*
August	–0.28	0.80**	0.95**	0.61*	0.02	0.49‡
	No rye					
Precipitation	Grain	Stover	Bottom	Top	Cob	Above-ear
Season	0.46*	–0.82**	–0.77**	–0.70**	–0.36	–0.67**
May	0.48‡	–0.74**	–0.61**	–0.65**	–0.45‡	–0.68**
June	–0.48*	0.76**	0.65**	0.66**	0.43‡	0.68**
July	0.31	–0.80**	–0.90**	–0.66**	–0.12	–0.50*
August	0.41‡	–0.84**	–0.85**	–0.71**	–0.28	–0.63**
Temperature						
Season	–0.32	0.80**	0.90**	0.66**	0.14	0.51*
May	–0.36	0.82**	0.89**	0.69**	0.19	0.56*
June	–0.42‡	0.84**	0.84**	0.71**	0.28	0.63**
July	–0.39	0.84**	0.87**	0.70**	0.23	0.59**
August	–0.19	0.68**	0.86**	0.55*	–0.03	0.34

* Significance at 0.05 probability level.

** Significance at 0.01 probability level.

*** Significance at 0.001 probability level.

† Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top–biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear–biomass yield of tops and cobs combined.

‡ Significance at 0.10 level.

Table 4. Corn grain and biomass yields across years (Y) and locations (L). E.V. Smith Research Center (EVS) near Shorter in central Alabama; Tennessee Valley Research and Extension Center (TVS) near Belle Mina in northern Alabama.

Plant part	2009 EVS	2009 TVS	2010 EVS	2010 TVS	2011 EVS	2011 TVS	Y × L
	kg ha^{-1}						*P* > *F*†
Grain‡	9251a§	7733b	5328d	7533b	6545c	5404d	≤0.0001
Stover	5482b	3732d	3486d	6706a	4713c	5752c	≤0.0001
Bottom	1696c	714e	954 d	2744a	1955b	1826bc	≤0.0001
Top	2593b	2064c	1522d	2917a	1842c	2664ab	≤0.0001
Cob	1186a	954b	1010b	1035b	916b	1262a	0.0001
Above-ear	3786a	3018b	2532c	3962a	2758bc	3926a	≤0.0001

† Probability of a larger *F* by chance among years and locations.

‡ Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top–biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear– biomass yield of tops and cobs combined.

§ Means within row followed by the same letter are not significantly different at the 0.10 level among the six location–years.

Table 5. Mean grain and biomass yields at E.V. Smith Research Center (EVS) near Shorter in central Alabama from 2009 to 2011 for all levels of cover crop and stover management.

Factor	Rye removed	Rye retained	No rye	Stover removed	Stover retained	Cover crop	Stover management	Cover crop × stover management
	kg ha^{-1}					$P > F$†	$P > F$‡	$P > F$§
			2009					
Grain¶	8732a#	9602a	9420a	9560	8943	0.9264	0.7711	0.9922
Stover	5133a	5600a	5714a	5524	5440	0.8320	0.9269	0.9560
Bottom	1460a	1684a	1944a	1653	1740	0.4092	0.7827	0.6205
Top	2550a	2668a	2582a	2646	2534	0.9638	0.7479	0.9948
Cob	1122a	1248a	1188a	1206	1166	0.8772	0.8582	0.9924
Above-ear	3672a	3916a	3770a	3871	3701	0.9381	0.7832	0.9975
			2010					
Grain	5289a	5675a	5021a	4894	5762	0.3627	0.0473	0.2192
Stover	3343a	3870a	3245a	3198	3775	0.1142	0.0423	0.2118
Bottom	971a	1117a	775b	917	991	0.0898	0.5664	0.3900
Top	1352a	1680a	1533a	1346	1698	0.3635	0.0976	0.6988
Cob	1020a	1073a	938a	935	1086	0.4734	0.1403	0.2983
Above-ear	2373a	2752a	2470a	2280	2783	0.4133	0.0707	0.4663
			2011					
Grain	4805 c	7850a	6979b	6232	6858	0.0940	0.5979	0.9687
Stover	3725b	5778a	4636ab	4555	4871	0.0326	0.6092	0.9458
Bottom	1495b	2371a	2001a	1849	2062	0.0783	0.5049	0.8696
Top	1417 c	2296a	1812b	1794	1889	0.0684	0.7591	0.9108
Cob	814b	1111a	823b	912	920	0.1537	0.9552	0.9800
Above-ear	2231b	3407a	2635b	2706	2809	0.0699	0.8068	0.9363

† Probability of a larger F by chance among levels of rye cover crop within individual years.

‡ Probability of a larger F by chance between levels of corn residue removal within individual years.

§ Probability of a larger F by chance among levels of Cover crop x Stover management interaction within individual years.

¶ Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top–biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear–biomass yield of tops and cobs combined.

Means within row followed by the same letter are not significantly different at the 0.10 level among the three levels of rye cover crop. Separation of means was achieved using the Tukey adjustment for multiple comparisons.

Table 6. Mean grain and biomass yields at Tennessee Valley Research and Extension Center (TVS) near Belle Mina in northern Alabama from 2009 to 2011 for all levels of cover crop and stover management.

Factor	Rye removed	Rye retained	No rye	Stover removed	Stover retained	Cover crop	Stover management	Cover crop × stover management
	kg ha^{-1}					$P > F$†	$P > F$‡	$P > F$§
			2009					
Grain¶	6577a#	8562a	8060a	7294	8172	0.6529	0.6604	0.9241
Stover	3433a	4158a	3606a	3257	4208	0.7011	0.2484	0.9619
Bottom	618a	825a	699a	635	794	0.7941	0.5673	0.9892
Top	1935a	2286a	1970a	1765	2363	0.7494	0.2048	0.9114
Cob	880a	1046a	937a	857	1052	0.6538	0.2471	0.9995
Above-ear	2815a	3333a	2907a	2622	3415	0.7019	0.1918	0.9480
			2010					
Grain	8033a	7285a	7110a	7162	7740	0.8253	0.6606	0.6675
Stover	6713a	7278a	6164a	6423	7014	0.6158	0.5552	0.7750
Bottom	2797a	3046a	2439a	2630	2891	0.5895	0.6185	0.9584
Top	2848a	3184a	2767a	2825	3040	0.7288	0.6547	0.6157
Cob	1067a	1051a	958a	968	1083	0.8400	0.5297	0.7188
Above-ear	3916a	4231a	3725a	3793	4122	0.7871	0.6101	0.6333
			2011					
Grain	4594a	5579a	6038a	5270	5538	0.5116	0.8114	0.8163
Stover	4820b	6101b	6197a	5660	5752	0.1189	0.8816	0.3721
Bottom	1736a	1936a	1876a	1846	1852	0.9349	0.9899	0.6992
Top	2503a	2731a	2834a	2665	2714	0.8087	0.9186	0.8880
Cob	974a	1324a	1487a	1214	1310	0.4688	0.7977	0.2780
Above-ear	3254b	4203a	4321a	3882	3970	0.0599	0.8241	0.2721

† Probability of a larger F by chance among levels of rye cover crop within individual years.

‡ Probability of a larger F by chance between levels of corn residue removal within individual years.

§ Probability of a larger F by chance among levels of Cover crop x Stover management interaction within individual years.

¶ Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top–biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear– biomass yield of tops and cobs combined.

Means within row followed by the same letter are not significantly different at the 0.10 level among the three levels of rye cover crop. Separation of means was achieved using the Tukey adjustment for multiple comparisons.

Table 7. Three-year average corn yields affected by the use of rye as a winter cover crop from 2009 until 2011 at E.V. Smith Research and Extension Center (EVS) in central Alabama and the Tennessee Valley Research and Extension Center (TVS) in northern Alabama.

Factor	Rye removed	Rye retained	No rye	Stover removed	Stover retained	Cover crop	Stover management	Cover crop × stover management
	———	———	kg ha^{-1}	———	———	*P* > *F*†	*P* > *F*‡	*P* > *F*§
			EVS					
Grain¶	6275a#	7709a	7140a	6895	7188	0.2039	0.6551	0.9366
Stover	4067b	5083a	4532ab	4426	4695	0.0415	0.4013	0.8220
Bottom	1309b	1724a	1573ab	1473	1598	0.0978	0.4267	0.8000
Top	1772a	2215a	1975a	1935	2040	0.1022	0.5259	0.9628
Cob	985a	1144a	983a	1017	1057	0.1331	0.5671	0.6940
Above-ear	2758b	3359a	2958ab	2953	3098	0.0754	0.5008	0.8980
			TVS					
Grain	6564a	7124a	7070a	6640	7199	0.6361	0.3069	0.3688
Stover	5161a	5667a	5322a	5135	5632	0.6340	0.2573	0.8466
Bottom	1817a	1777a	1671a	1679	1831	0.8900	0.5715	0.9315
Top	2474a	2670a	2524a	2422	2689	0.6550	0.1087	0.4371
Cob	983a	1152a	1127a	1025	1150	0.2982	0.2037	0.1409
Above-ear	3387a	3884a	3651a	3455	3827	0.1745	0.0882	0.5606

† Probability of a larger *F* by chance among levels of rye cover crop.

‡ Probability of a larger *F* by chance between levels of corn residue removal.

§ Probability of a larger *F* by chance among levels of Cover crop × Stover management interaction.

¶ Grain–corn grain yield; Bottom–biomass yield from the base of the plant up to the first ear; Top–biomass yield from the first ear excluding cobs and grain; Cob–biomass of cobs; Above-ear–biomass yield of tops and cobs combined.

Means within row followed by the same letter are not significantly different at the 0.10 level among the three levels of rye cover crop. Separation of means was achieved using the Tukey adjustment for multiple comparisons.

At TVS, none of the factors studied had a statistically significant effect on grain yield during the 3 yr of the experiment (Table 6). However in 2011, the greatest grain yields were observed in plots without a rye cover crop. As mentioned earlier, this could be due to the extensive flooding that occurred at tasseling growth stage (VT). The clayey soil texture, in combination with rye covering the soil surface, could have reduced the evaporation of the excessive water and induced the negative impacts of flooding on grain yields. Nevertheless, the general trend of greater yields in plots with a rye cover crop at both locations might be due to a cumulative effect of cover crop use on soil properties. Similarly, Duiker and Curran (2005) reported it takes several years to observe the benefits of a cover crop. Additionally, a cover crop could cause microclimate interaction that can increase soil water retention properties and affect soil heating properties during the spring.

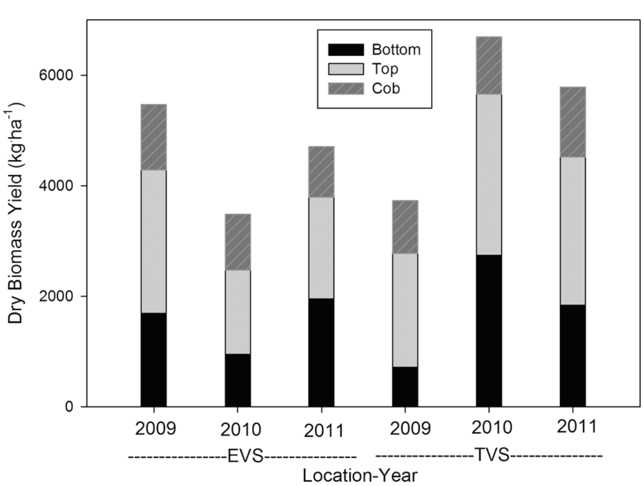

Fig. 1. Three-year average incremental biomass yields (kg ha^{-1}). E.V. Smith Research Center (EVS) near Shorter in central Alabama; Tennessee Valley Research and Extension Center (TVS) near Belle Mina in northern Alabama.

At EVS, the 3-yr average effect of rye and stover residue retention in the field resulted in the greatest corn grain yield; nevertheless, the observed trends were not statistically significant (Table 7). This observation is in agreement with a 11-yr study conducted in a silt loam in Indiana (Barber, 1979). In the Indiana study, average grain yield was greater in plots where residues were retained than in plots where residues were removed; however, the difference was not statistically significant. When examining the 3-yr average effect of the independent variables on grain yield at TVS, the use of a rye cover crop and stover management resulted in a statistically nonsignificant yield increase (Table 7). These results are in agreement with Barber, (1979) and another study with no-till and rye cover crop which was in a silt loam soil (Duiker and Curran, 2005). In the 2005 study, the 3 yr average effect of a rye cover crop increased corn yield; nevertheless, the observed difference was not statistically significant.

Corn Biomass Yields and Vertical Distribution

All corn biomass yields varied significantly among the six location–years (Table 4). This was not surprising due to the variations in weather and soil types between the central and the northern part of the state. Despite climate variations, there was no distinct pattern in total and partial stover yields across years (Fig. 1). For the first 2 yr at both locations, there were no indications that use of a rye cover crop and stover removal had a significant effect on corn biomass yields (Tables 5 and 6). However, in 2011, which was the third year of the study, the effect of cover crop was significant on all stover yields at EVS, apart from the cob portion. No significant differences were observed at TVS in 2011. The flooding conditions, that reduced yields compared to the previous years of the study (Tables 4 and 6), probably diminished the effects of residue management on corn biomass yields at TVS.

The 3-yr average total biomass yield at EVS was maximized where the rye cover crop was retained (5083 kg ha^{-1}). That yield was significantly greater ($p = 0.0415$) from plots where rye was removed by 20% and no rye plots by 11% (Table 7). At TVS, plots where rye was retained also produced the largest amount of total biomass; however, differences from the other rye treatments were not statistically significant. At the TVS location of this study, retention of rye in the field increased stover yields compared to plots where rye was removed, but stover yield was no different to the no-rye plots. This contradicts results reported by Raimbault et al. (1990) that rye in combination with no-till in a loam soil decreased corn biomass yield and retarded crop growth. However, their study was conducted in Ontario, Canada, and the colder climate in that region could cause a delay in spring soil warming, which might explain the adverse response they reported.

The bottom and top fractions of the plant exhibited a similar yield response from the treatments compared to the total stover yield. At EVS, maximum yields were observed where rye was retained in the field; nevertheless, the difference compared to no rye plots was not significant (Table 7). At TVS, yield differences among rye treatments were statistically insignificant.

At both locations of the study, the 3-yr average cob yields were similar, 1037 kg ha^{-1} and 1084 kg ha^{-1} in the central and northern part of the state, respectively. At EVS, retention of rye in the field resulted in 14% higher cob yield than plots without the use of a cover crop and plots where rye was removed in spring; however, the difference was not statistically significant ($p = 0.1331$, Table 7). A similar yield trend was also observed at TVS ($p = 0.2982$, Table 7).

In 2011, which was the last year of the experiment, the above-ear biomass at EVS was higher in plots where rye was retained (Table 5). A similar trend was also observed at TVS; although, the effect was not significant (Table 6). At both locations, the 3-yr average maximum above-ear yields where observed in the rye retained treatment (Table 7). The 3-yr average effect of rye on the above-ear portion was significant only at EVS ($p = 0.0754$); nevertheless, the difference compared to no rye plots was not significant (Table 7). The 100% of stover removal significantly lowered yields only at TVS ($p = 0.0882$). The lower yields in plots where stover was removed at TVS highlight the importance of evaluating regularly the possible impacts of biomass removal on soil quality and possible implications in long-term biomass production. Such impacts include soil nutrient depletion (e.g., K) due to rye and stover harvest. Therefore, it is imperative to account and replace nutrient loss via fertilization every year.

During all 3 yr of this study, the average yield of cobs accounted for about 21 to 23% of total biomass, while the above-ear fraction was the highest portion of the stover at both locations. The above-ear biomass accounted for 67 and 69% of the total stover, with the remaining 33 and 31% consisted of the bottom portion at EVS and TVS, respectively. Averaged over all 3 yr of the experiment, the stover/grain ratios were 0.66 and 0.81 at EVS and TVS, respectively. The low ratios could have resulted due to leaf loss during the dry down period since the samples were collected at grain harvest. These results vary from those which have been reported by Wilhelm et al. (2011) in a multi-location study where the above-ear biomass and cobs alone accounted for 50 and 18% of total stover, respectively. However, the stover/grain ratios at grain maturity were similar to the range reported among the locations of their study (0.64–1.1).

In this experiment, the data did not clearly show that the 3-yr 100% corn residue removal significantly affected the yield parameters studied at either location. Additionally, the use of rye as a winter cover crop, when retained in the field in the third year of the study, the corn stover yield increase became significant. It is interesting though, that corn grown where rye was removed in spring resulted in similar or lower yields compared to plots where rye was retained or no-rye plots at both locations. As reported in previous studies, high rye yield can deplete the moisture in the soil surface (Ebelhar et al., 1984; Raimbault et al., 1991). Then, removing the rye could result in unfavorable initial conditions for corn production, such as unprotected soil surface and reduced soil moisture content, which can impact final yields. Nevertheless, the contribution of rye on soil organic matter, even when harvested in spring, should be considered. According to Barber (1979), the roots of crops that have been harvested can assist to maintain SOC levels.

CONCLUSIONS

Weather conditions during the six location–years of the experiment varied significantly. However, significant correlations were detected between precipitation and temperatures and corn grain and biomass yields. In addition to rainfall and air temperature differences between the locations, differences in soil types could have also contributed to the variability in corn yields. Data from this study suggest that a rye cover crop could be used as a management practice to reduce the impact of year-to-year weather variability on corn productivity across humid subtropical climate in Alabama.

Results from this 3-yr study indicate that the use of winter rye as a cover crop had no significant effect on grain yield. Retention of a rye cover crop increased biomass yields compared to rye removal in central Alabama while there was no difference compared to no rye plots. However, there was no significant effect of using a rye cover crop in the northern part of the state. Furthermore, 3 yr of corn residue removal had minimal effect on almost any of the plant yield parameters studied at either location. Vertical fractionation of corn biomass could result in significant amounts of biomass that could be harvested as biofuel feedstock while leaving a portion of the plant residue in the field for erosion control and soil organic matter maintenance. Based on this study, harvest of the above-ear corn plant fraction could be an attractive option for partial biomass harvesting. Nevertheless, it is important to evaluate other effects, not discussed in this paper, such as soil C sequestration and long-term sustainability. The effect of partial biomass removal on corn yields and soil properties should be monitored and assessed in long-term studies.

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